International Journal of Disaster Risk Reduction 31 (2018) 589–601

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Development and Implementation of a DECATASTROPHIZE platform and tool for the management of disasters or multiple hazards

A. Damalas[a,*], C. Mettas[a], E. Evagorou[a], S. Giannecchini[b], C. Iasio[b], M. Papadopoulos[c], A. Konstantinou[c], D. Hadjimitsis[a]

[a] *Cyprus University of Technology, Faculty of Engineering and Technology, Department of Civil Engineering and Geomatics, ERATOSTHENES Research Centre, 2-6 Saripolou Street, 3603, Limassol, Cyprus*
[b] *GeoSolutions, Via Carignoni 51, Camaiore, Italy*
[c] *Ministry of Interior, Cyprus Civil Defence, Cyprus*

ARTICLE INFO

Keywords:
Disaster management
Geo-spatial Early Warning Decision Support System
Multi-Hazard or Disaster Risk Assessment
Humanitarian Aid and Civil Protection (ECHO)
European Union (EU) Civil Protection Mechanism

ABSTRACT

Research studies using a Geo-Spatial Early Warning Decision Support System (GE-DSS) based platform and tool to integrate and link decision makers, Emergency Operation Centres (EOCs), Operational Resources (OR) in the field for multi-hazard or disaster management in accordance relative to the New European Union Civil Protection Mechanism (UCPM) priorities have neither been explored nor implemented. The goal of the DECATASTROPHIZE (DECAT) platform is to use a GE-DSS to assess, prepare for and respond to multiple and/or simultaneous natural and man-made hazards and disasters in a synergistic way on one multi-platform, distributed and integrated framework. The main results of the DSS platform include:1) GE-DSS use-case analyses, workflows and functionalities for early warning, decision making and rapid mapping, 2) methodologies for rapid assessment and mitigation of impacts, and 3) Spatial Data Infrastructures (SDI) from Cyprus for disseminating geospatial data and information about various types of multi-hazards with dedicated capabilities aimed to support impact assessment as well as emergency management based on activities suitable for overall operational scenarios.

In addition to integrating the a) GE-DSS, b) EOCs, and c) OR in the field, the DECAT methodological framework software also integrated hazard/risk assessment with the common operational picture. The paper aims to introduce the GE-DSS prototype resulting from the implementation of these requirements, resulting by reuse, improvement and extension of Open Source SDI codes. It has been already tested in all of DECAT participating countries. The objectives achievement level was evaluated by analysing the test performed by Cyprus Civil Defense (CCD).

The DECAT project aimed to a) demonstrate the assessment and mitigation of impact of natural disasters, b) discuss and develop effective warning systems decision making and rapid notification for risk resilience at all levels, c) stimulate exchange of ideas and knowledge transfer on all phases of the disaster management cycle including disaster research, and risk reduction at all geographical scales—local, national and international, d) assess multi-disaster risk and impacts from a multidisciplinary and multi-faceted perspective, e) develop multi-disaster risk reduction strategies and techniques.

Abbreviations: BRGM, The French Geological Survey / Bureau de Recherches Géologiques et Minière; CCA, Climate Change Adaptation; CCCCC, Caribbean Community Climate Change Centre; CCD, Cyprus Civil Defense; COP, Common Operational Picture; CPX, Command Post Exercise; CSW, Catalog Services; DEC, Department of Electronic Communications; DECAT, DECATASTROPHIZE; DLS, Department of Lands and Surveys; DoF, Department of Forest; DoFMR, Department of Fisheries and Marine Research; DRR, Disaster Risk Reduction; DSS, Decision Support Systems; EAC, Electricity Authority of Cyprus; ECC, Emergency Coordination Centre; ECHO, Humanitarian Aid and Civil Protection; EOCs, Emergency Operation Centres; EU, European Union; EWS, Early Warning Systems; ExCon, Exercise Control Team; FAO, Food and Agriculture Organization; FS, Fire Service; GE-DSS, Geo-Spatial Early Warning Decision Support System; GSD, Geological Survey Department; GIS, Geographical Information Systems; GPS, Global Positioning Systems; GSD, Geological Survey Department; ICT, Information and Communications Technology; IFSAR, Interferometric Synthetic Aperture Radar; MPHS, Medical and Public Health Services; NATO, North Atlantic Treaty Organization; NGAC, National Geospatial Advisory Committee; NHRR, Natural Hazard Risk Reduction; OAS, Organization of American States; OGC, Open Geospatial Consortium; OR, Operational Resources; PD, Police Department; PWD, DLS, Public Works Department; RS, Remote Sensing; SDI, Spatial Data Infrastructure; SDSS, Spatial Decision Support Systems; SPCA, spatial principal component analysis; SS, Statistical Service; TTX, Table Top Exercises; UCPM, Union Civil Protection Mechanism; UNEP, United Nations Environment Program; US, United States; WCS, Web Coverage Services; WDD, Water Development Department; WFP, World Food Program; WFS, Web Feature Services; WMS, Web Map Services; WPS, Web Processing Services

* Corresponding author.
E-mail address: andreas.damalas@cut.ac.cy (A. Damalas).

https://doi.org/10.1016/j.ijdrr.2018.05.011
Received 30 December 2017; Received in revised form 12 May 2018; Accepted 23 May 2018
Available online 21 June 2018
2212-4209/

1. Introduction

In the past four decades, great progress has been made in the development of geospatial data and tools that describe locations of objects on the Earth's surface and make it possible for anyone with access to the Internet to witness the magnitude of a disaster. Spatial Decision Support Systems (SDSS) evolved from Decision Support Systems (DSS) and Geographical Information Systems (GIS). GIS, Remote Sensing (RS), and Global Positioning Systems (GPS) gained much attention for their applications in disaster management and are increasingly utilized throughout the entire disaster management cycle as a tool to simplify field operations tracking as well as to support decision making [12,19,25,29,31,39]. In addition, in all aspects of emergency management, geospatial data and tools have the potential to help save lives, mitigate damage, and reduce the costs of dealing with emergencies. Hurricane Katrina in 2005 severely taxed and in many cases overwhelmed responding agencies [27].

Many published reviews, reports and studies over the last two decades document these applications and the integration of GIS, RS and GPS systems for the systematic assessing and monitoring of natural hazards has been started to be used as an effective tool. In the Primer on Natural Hazard Management in Integrated Regional Development Planning, the OAS [32] devotes one chapter on RS in natural hazard assessments and another chapter on GIS in natural hazard management. The former chapter provides planners with an overview of remote sensing technologies and their general application in natural hazard assessments. Characteristics of both aerial and satellite RS techniques and the role RS can play in detecting and mitigating several natural hazards are highlighted. The latter chapter introduces the planner to the concept and applications of GIS for natural hazard management in the context of integrated development planning. The chapter also discusses the acquisition of a GIS, the elements involved in making that decision, and the basics of how to select, establish, and use such a system. One early example and study showed that geospatial analysis, mapping and digitizing watershed and sub-watershed hydrologic unit boundaries can be used for flood risk management Damalas [9].

An investigation on the value of Interferometric Synthetic Aperture Radar (IFSAR) geospatial data, products and services for emergency management, flood modelling and risk assessment was conducted by Li et al. [22]. It suggested that it provides insight into the value of three-dimensional (3D) geospatial data products and services of Intermap Technologies as well as the significant role these products and services play in support of emergency management with the emphasis on flood risk assessment.

Published studies on the integration of GIS and natural hazards are well documented and reviewed by Tarolli and Cavalli [40]. They elaborated on many of these studies and stated that the GIS technology (commercial, open source, and web-based) offered to the scientific and technical community a powerful tool to analyze natural processes. Research studies show that natural hazards, such as earthquakes, landslides, debris flows, floods, volcanic and seismic activity, hurricanes, coastal erosion, and wildfires, but also droughts and human diseases (e.g., malaria and cholera), are now easier to manage and understand, thanks to the introduction of GIS. Further, in the field of natural hazards, the increasing availability of GIS coupled models and decision-support tools offers even more efficient support for governmental agencies and decision makers to help in risk management and protection activities. How remote sensing contributes to assessing earthquake risk was reported by Geiß and Taubenböck [14]. Based on a literature review and a discussion of scientific trends and current research projects, first steps towards a roadmap for remote sensing were drawn, explicitly taking scientific, technical, multi- and transdisciplinary as well as political perspectives into account.

Soil erosion hazards were assessed using a raster-based GIS approach with spatial principal component analysis (SPCA) [35]. Their study highlighted that priority should be given where the actual occurrence is high to very high and the probability of potential risk is average to high for protecting the land at present and in the future as well. Therefore, the application of spatial principal component analysis (SPCA) combined with RS and GIS provided an effective methodology to solve the complex decisional problem for soil erosion hazard and risk assessment.

In fact, and more recently in the Eastern Med region, several examples have also been reported. For instance, [26] stated that remote sensing techniques can be used to eliminate risks due to physical and natural hazards by continuous monitoring of infrastructure like asphalt pavement structures. Also, integration of remote sensing, GIS and predictive modelling for landslide hazard zonation was achieved according to Alexakis et al. [2].

The military influence in this technology evolution is very pronounced. The visualization capabilities of these systems have almost become expected by policymakers, disaster managers, and even the public, as the status of technology knowledge and dissemination makes them potentially available also for civilian applications.

On the other hand, the complexity of disaster response operations, usually engaging organizations with heterogeneous level of preparedness and training, makes critical to apply advanced tools to properly share even basic geospatial information. The proper tool should be then available to allow easy access to training and exercise, based on user interfaces a civilian is familiar with. A SDSS engine made by even complex geospatial database and models, should show an interface and a real-world model representation resembling geospatial tools people is becoming more and more familiar with by daily usage of location-based services provided by smartphones apps, and common web-based geospatial applications.

Relative to disaster studies and emerging geospatial technologies and the geospatial landscape are reviewed in a Report of the NGAC [30]. The report identifies five overarching technology trends driving geospatial technologies, and then examines within this context the impacts on federal agencies in the core geospatial activity areas of data collection and generation, data analytics, infrastructure, access, and workforce. Currently, most geospatial applications, including those for emergency management purpose, are not limited to specialized tools, available and usable only for an elite of selected experts, which usually becomes too restricted when a disaster occur.

The potential to use mobile technology to complement conventional data sources, GIS, RS and GPS to address issues of disaster and emergency management is proposed in several reports; an example of a wireless mobile field-based GIS for crisis management process is provided through a case study of a fire event in Cairo, Egypt [10].

Integration of mobile technology into geospatial analysis and emergency management is shown by Liu et al. [23]. They pointed out that with the rapid growth of mobile devices and applications, geotagged data is becoming increasingly important in emergency management and has become a major workload for big data storage systems. After an analysis of the requirements and challenges on geospatial big data storage in emergency management, discussions followed with individual perspectives from practical cases. The paper focused on how to develop a geospatial data storage platform and on how to approve the rationality of geospatial big data system which they planned to build.

The DG-ECHO funded DECAT project which aimed to create better prerequisites and to improve preparedness for civil protection professionals and volunteers, within the framework of the Union Civil Protection Mechanism and to improve and complement the performance of participating states organizations involved in the protection of citizens, environment and property in the event of natural and man-made disasters. The DECAT consortium payed particular attention to define requirements for the development of SDSS tools able to go beyond the constraints and limitations remarked above, starting from a use case framework covering the most critical and conventional phases of the disaster management cycle.

To mitigate the lack of or difficulty in understanding the concept of the DECAT framework, as there is, in particular, a general tendency or reluctance not to prepare for the occurrence of "multi- hazards" and to focus on a "paradigm" change in Civil Protection preparedness, the awareness and/or dissemination of knowledge campaigns and the training and information sessions or seminars intended to contribute largely to clarify the aforementioned aims.

The manifold objectives of the work described in this paper are: to test in Cyprus the SDI's developed within the scope of DECAT project, for disseminating geospatial data and information about various types of hazards (primarily fires and floods) with dedicated capabilities aimed to support impact assessment as well as emergency management based on activities suitable for overall operational scenarios, to use the GE-DSS in use-case analyses, workflows and functionalities for early warning, decision making and rapid mapping and to improve methodologies for rapid assessment and mitigation of impacts taking advantage from the developed SDI.

The state of the art regarding the use of SDSS, DSS or a combination of such technologies can be observed in this paper, while the methodology used and the outcomes of the DECAT tool are also described.

2. Literature review and previous experiences

The use of SDSS for a variety of natural hazard risk, disaster and hazard mitigation and preparedness purposes has been described by a number of authors in various publications [29]. Over recent decades, the development of single hazard models for hurricane impact using GIS have become a major topic of research [8,13,16,19,38]. Despite the disastrous effects of hurricanes on coastal and inland communities are well known [31,34,45], there is still a need to better understand how to manage vulnerability to the different mechanisms related to hurricanes strike like storm surges, floods and high winds [12]. Applications by Merrett and Chen [25] showed that GIS with RS data provided the ability to effectively analyze various risk factors over large and inaccessible areas to identify localities which have the potential to be at higher risk from the impact of (single) disaster types such as landslides, debris flows and earthquakes. Their reason for choosing these disaster types specifically was that, as there was a unique approach to hazard modelling, they found a number of consistencies in data requirements and model development.

Approaches based on the development of single hazard models using SDSS, and RS for fire risk assessment, application domains using RS and SDSS for fire prevention, impact fire management and fire effects assessment have also become a major topic of research in hazard or disaster management [15,7]. Applications focusing on fire response included SDSS for the assessment of the propagation and combating of forest fires in Greece [5]. Other emergency and hazards related SDSS publications included SDSS for managing possible landslides through the integration of real-time monitoring systems in the SDSS [21], and flood area delineation in transboundary areas [24]. Basic applications, using a Multi-Hazard model method, were applied to hurricane hazards and elements at risk assessment using GIS data [4,6,42]. One more developed application, based on "Multi-Hazard" (MH) methods, is HAZUS (Hazards US). MH refers to Earthquakes, Hurricanes, and Floods which can/will continue to occur. It is a nationally applicable standardized Earthquake, Wind, Flood methodology and multi-hazard risk assessment and loss estimation software program developed by the US Federal Emergency Management Agency [11]. Natural hazard risk is largely projected to increase in the future, placing growing responsibility on decision makers to proactively reduce risk. Consequently, DSS for Natural Hazard Risk Reduction (NHRR) are becoming increasingly important. A review of 101 papers [29] indicates that most effort has been placed on identifying areas of risk and assessing economic consequences resulting from direct losses from single hazards. However, less effort has been placed on testing risk-reduction options and considering future changes to risk from multi-hazards. Furthermore, although there are some similarities between DECAT GE-DSS and DSS's for NHRR, there was limited evidence within the reviewed papers on the success of DSSs in practice and whether stakeholders participated in DSS development and use and the state of the art about usage of SDI and Geospatial software tools for disaster response and emergency planning, finding gaps with respect to the DECAT proposed approach and tool.

EWS have been an important factor in reducing the risk of death and injury to people, loss to property and damage to environmental resources triggered by natural disaster or hazards related to fire, flood (water), climate and weather. The International Network for Multi-Hazard Early Warning Systems [18], a Multi-Stakeholder Partnership for Promoting and Sharing Best Practice in Multi-Hazard Early Warning Systems and Services for Disaster Risk Reduction (DRR) and Resilience, published a concept paper calling for "Multi-Hazard Early Warning Systems". The Concept Paper consists of its Rationale (Background, Recent Advances in Early Warning Systems, Challenges related to Early Warning Systems, The Call for Multi-Hazard Early Warning Systems) and describes the IN-MHEWS (Objectives, Strategies, Initial Activities and Outputs, Coordination, Network, Partners). The underpinning strategy for the IN-MHEWS is to utilize existing frameworks to complement existing and emerging strategies for DRR and Climate Change Adaptation (CCA) which will help in supporting a wider strategic approach to enhance the quality and optimize the level and scope of early warning systems for society. The approach included eleven sub-strategies of which one is to promote the shift from a single-hazard approach to a multi-hazard approach for EWS.

It's a fact that conceptual use (IN-MHEWS 2015; [41,43]) applications and role of GIS, RS or SDSS for a variety of single and multiple disaster and hazard mitigation and preparedness purposes, natural disaster hazard assessment and mitigation [25], emergency management applications [1], GIS for multi-hazard risk assessment case studies have been presented in courses [47] and texts discuss the contexts, perspectives and management of Environmental Hazards and Disasters [33]. Moreover, there is still a need to better understand the need for local and higher resolution mapping and multi-hazard risk assessment, the application of the DRR Cycle for integrated and multi-hazard or disaster management, and the importance to systematically analyze and assess risks in integrated manner using multi-hazard, natural systemic or people centered approaches i.e., ecological, hydrological, geomorphological [37].

At this time, there are no application domains or research studies using a GE-DSS based platform and tool to integrate and link decision makers, EOCs, and ORs in the field for multi-hazard or disaster management in accordance relative to the UCPM priorities that have either been explored or implemented. The purpose of the DECAT platform and tool is to use geo-spatial early warning GE-DSS to assess, prepare for and respond to multiple and/or simultaneous natural and man-made hazards, disasters, and environmental incidents in an integrated and synergistic way on one multi-platform, distributed and integrated framework. Because of the need to integrate and manage all these factors and aspects relative to multi-hazard and disaster data and models, early warning, decision making and rapid mapping, GIS appears to be the most appropriate tool to deal with those tasks and using GE-DSS combined with integrated GIS solutions fuses text and geographic information into one model and view. In addition to integrating the a) GE-DSS, b) EOCs), and c) OR in the field, the DECAT methodological framework software also integrated hazard/risk assessment with the common operational picture.

Consortium members responsible for the design and implementation of the DECAT DSS have been involved in similar exercises for various organizations including United Nations Environment Program (UNEP), World Bank, Food and Agriculture Organization (FAO), World Food Program (WFP), Italian Civil Protection, Caribbean Community Climate Change Centre (CCCCC) and North Atlantic Treaty Organization (NATO) in which they have been able to observe that a

vast number of online platform have been developed over the years focusing either on specific hazards or on specific phases of the disaster cycle and emergency management.

Learning from these experiences, one of the underlying objectives is to create a platform based on well-known Open Source products to pave the road towards creating a comprehensive modular spatial data infrastructure that would cover all the phases of the emergency for different types of hazards with clear extensions points to address future requirements and changing technologies and a special focus on exposing secure but standard protocol interfaces for interacting with external system; this point marks an important different with many existing systems which tend to work in a stovepipe fashion with no possibility to interact with external services, which is also a key feature of platforms like DECAT DSS which should aim to complement and interoperate with existing ones and not to replace them.

The added value of the DECAT platform is that it reflects the primary goal of DG ECHO to enhance preparedness in European civil protection through its bottom-up approach to technological innovation in cross border civil protection and marine pollution cooperation, including regional cooperation by integrating early warning, impact assessment and mitigation of impacts for multi-hazards simultaneously. It improves Coordination, effective and efficient Decision Making During a Disaster relative to 1) Proximity of Operational and relevant Resources, 2) Services provided by Civil Defense, communication with Ministers and Media, 3) the population dispersion, transportation, safe route accommodation, facilities and communications, 4) fire-fighting coordination 4) first aid teams 5) host nation infrastructure support. In addition, DECAT provides continuous COP. updates by editing annotations within the DECAT DSS Mitigation of Impact module and provides a geospatial overview of rescue and recovery teams engaged in the field and their level of adequacy to site specific incidents they are facing. The possibility to reevaluate the impact assessment provides a more truthful background to emergency response operations, making DECAT platform an adaptive and easy-to-use tool to implement the situations awareness mechanism.

3. Methodology for the development

3.1. Data and methods

The approach of DECAT was based on a unique process applying an integrated and innovative multi-hazard geospatial approach to prevention and preparedness priorities focusing on multi-hazards to develop early-warning alert systems and improve decision making. The methodology of DECAT tool included 1) the design of the GE-DSS for the DECAT platform; 2) the development and use the platform to link and integrate components (data and models) into one view used in prediction, prevention and preparedness for multi-hazards and decision-makers with civil protection resources 3) activities to advance, enhance monitoring of a) wildfires b) active floods, prediction of flood hazard danger and potential, mapping of flood risk; and 4) methods to test and implement innovative techniques to link prediction, prevention measures to preparedness and response needs. Once the design features were established, the components of the GE-DSS were assembled. Specifically, DECAT established geo-databases for test areas and the DECAT platform consists of six databases (i.e., one in each partner country) and each one managed and monitored its own GE-DSS and their results during Table Top Exercises (TTX). The platform was tested in realistic scenarios to confirm that it can improve decision making in emergencies (Table 1).

The Workflow diagram for the creation of DECAT's framework is presented in Fig. 1. The first phase of the project was the collection of data and models, as can be seen in Fig. 1A. Different governmental organizations (Department of Lands and Surveys (DLS), Public Works Department (PWD), Water Development Department (WDD), Department of Forest (DoF), Fire Service (FS), Geological Survey Department (GSD), Department of Electronic Communications (DEC), Department of Fisheries and Marine Research (DoFMR), Statistical Service (SS), Medical and Public Health Services (MPHS), Electricity Authority of Cyprus (EAC) and Police Department (PD)) contributed to the collection of data and models. Thanks to the participation of all these departments, plethora of data was collected and analysed. (Table 2)

Table 1
Hazards scenarios on TTX's for each partner country.

Country	TTX - Hazards Scenarios
Cyprus	Fires & Floods
France	Earthquake
Greece – Crete	Earthquake/Tsunami, Fires, Marine pollution – oil spill
Hungary	Floods and Fires
Italy	Flood
Spain	Fires

For fire/wild fire models, a combination of a high-risk static map with many related layers entered the geodatabase. Also, a dynamic GIS model for floods has been designed as to be compatible to the DECAT framework. Flood models were based on WDD's data and models which were created in June 2014 for nineteen areas [46]. The aim of the flood tool was to compute and delimit areas vulnerable to floods.

Once the design features were established, the documents and geospatial data were assembled in the DSS. More specifically, a Geodatabase enriched the DECAT framework (Fig. 1_B), by the integration of geographical details of elements in different layers and hazard data models (Fig. 1_C).

3.2. The DECAT DSS platform

The DECAT DSS comprises of several modules providing the functionalities required to support the three main phases of the emergency management: Early Warning, Impact Assessment and Mitigation of Impact (Fig. $1C_{1-3}$) plus a few modules (Fig. 2) providing generic functionalities that are needed by all three phases above (i.e. document management, geospatial data management and user management).

The platform makes extensive use of interoperable protocols to support geospatial data dissemination as it supports various Open Geospatial Consortium (OGC) protocols. Thanks to its meta-model, the DSS can be configured to ingest and disseminate new outputs derived from third-party software but it can also directly integrate OGC Web Processing Services (WPS) [36] to provide advanced geoprocessing capabilities for performing impact assessments. So that, the system can be configured to ingest both in programmatic terms as well as in terms of functionalities. Several extension points are provided to give developers the possibility to extend and customize system's behaviour.

Despite the focus on integration and interoperability, special care has been given to securing access to data and functionalities. Data access has to be set by the data owner using a highly granular pre-set of permissions. Moreover, authenticated users act with a specific role, which allows to use only the selected set of functionalities they need for their own activities. As an instance, only the Event Operator role will be allowed to create and manage alerts and promote them to Hazardous Events, triggering the workflow consisting in impact assessment and consequent emergency management.

3.3. A comprehensive workflow from early warning to emergency management

The DECAT DSS modules provide the Information and Communications Technology (ICT) operator in emergency management with specific tools and customized environments for each phase of emergency management.

The **"Early Warning"** module provides the "Event operator" with wizards to create, edit and update different events occurring inside his

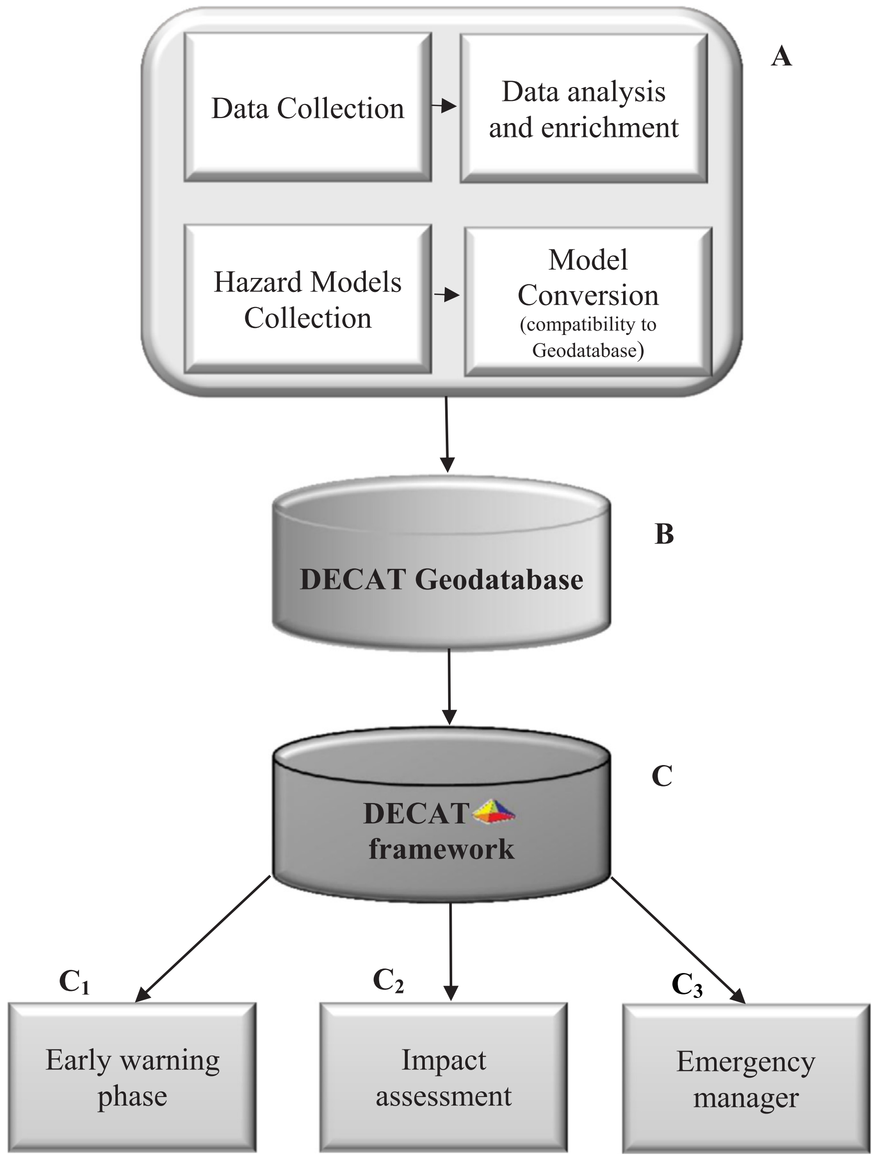

Fig. 1. DECAT TTX Workflow.

area of competence.

The “Early Warning” module provide the user with geospatial tools to edit point features and record ancillary information useful to characterize the event and assess the current level of hazard, generally used to revise and debrief the emergency response. Each evolving event can be searched, modified and updated, to evolve to an occurrence treating the community or back to ordinary conditions. In the first case, it will be “promoted” and notified as early warning, otherwise it will be archived (Fig. 3); once an event is promoted the other phases are enabled and the entire workflow to assess the impact and manage the emergency comes to life.

The **“Impact assessment”** module allows the “Impact assessor” (i.e. a domain expert with scientific background and experience regarding effects and losses occurring because of a specific type of disaster) to evaluate the context and the environment where the event is taking place, providing by modelling or pre-formulated scenario analyses, additional geospatial information, reports and documents useful to properly identify and locate specific needs of rescue and recovery interventions. This module has been designed to permit the creation and update of the so-called “Common Operational Picture” (COP) for the emergency managers, which is an evolving geospatial representation of the hazards integrated with preliminary localization of rescue and recovery targets, by integrating relevant hazard models outputs directly in real-time (through calls to external models exposed via the OGC WPS protocol) or indirectly (via the guided upload of outputs from offline runs of external models).

The “Impact assessor” thus has the possibility to create a reference map (the COP) for the emergency management coupling hazards modelling together with geospatial information relevant for emergency plan implementation (e.g. gathering areas, field hospital location, command and control field unit) as well as targets needing urgent intervention. The symbols used to visualize the feature can be adapted to the subject and changed according to its specific evolution. The COP can then be frozen to a specific instant, and shared with the emergency managers, responsible to assign rescue or recovery targets to work-force teams (Fig. 4), however the Impact Assessor can, at any time, perform a new assessment by updating information in the active COP to create an updated one that would more closely represent the current situation.

The last set of functionalities is related to workforces’ coordination and **“Emergency Management”*;*** this module the platform provides the Emergency Managers with capabilities to collaboratively (and concurrently) manage online, directly on the COP geospatial features representing allocated teams, customized according to the type of workforce they belong. Such geospatial features can be updated over

Table 2
A description of the data (sets), including 1) data providers, 2) database/data model name, 3) format of the data, 4) coordinate system in each country, and 5) nature of the data used in the platform is presented.

Geospatial Data uploaded on DECAT framework for Cyprus
Coordinate system: WGS 84 / UTM zone 36 N

A/A	Data product	Feature type	Source of the data	Description of data and meta-data
1.	Forest fire stations, Fire stations, Fire observation points and lookout stations (FLOS), Fire Data	Point	DoF, FS	1. Physical address and contact details 2. Commanding Officer (or equivalent) and Executive Officer (or equivalent): name, rank, contact details 3. Number and types of fire engines serviceable in fire station 4. Number of firefighters on duty per shift 5. Historical data for fires
2.	Areas of Extreme, High, Moderate and Low Risk	Polygons	DoF	Areas of fire risk
3.	Coastline	Lines	WDD	Data that shows the Coastal Erosion of Cyprus
4.	Cyprus Civil Defence (CCD) offices	Point	CCD	Data that shows CCD offices
5.	Fire Protection Buffer Zone	Polygon	DoF	Buffer zones from the State Forest that Department of forest take action in case of fire
6.	SCI_areas, SPA areas	Polygon	DLS	Special Areas of Conservation (SAC's)
7.	CORINE Landuse 2000, Overlay	Polygon	WDD	Land Use
8.	Banks,Bridges,Closed Sections, Flow Linear, Flowpaths, Inline Structures, River,	Lines	WDD	Separate lines data for 19 areas of Cyprus which will be used to the model of Flood
9.	District Line	Lines	DLS	Boundaries of Districts
10.	Villages, Population	Polygon	DLS,SS	Boundaries of the Villages. Information about the presidents of the communities and the population of each village
11.	Roads	Lines,Polygons	DLS, PWD	Transportation grid
12.	Hospitals and medical centres	Points	MPHS	1. Physical address and contact details with hospital Administrator: name, contact details
13.	Remote Sensed data for modelling floods	Raster	WDD	Separate lidar data for 19 areas of Cyprus which will be used to the model of Flood
14.	Police stations	Points	PD	1. Physical address and contact details 2. Commanding Officer (or equivalent) and/ or Executive Officer (or equivalent): name, rank, contact details 3. Number and types of units serviceable in police station
15.	Schools	Points	DLS	Data shows the locations of schools

time to capture the status of resources engaged with the rescue operations on the field (Fig. 5) as well as the changing conditions on the field. Moreover, updates of the COP generated by newer impact assessment to capture the evolution of the disaster can be published at any time by the Impact Assessor and they will refresh background information used by the Emergency Managers.

The whole system is designed to simplify and speed up geospatial information sharing and disseminate a geospatial representation of COP

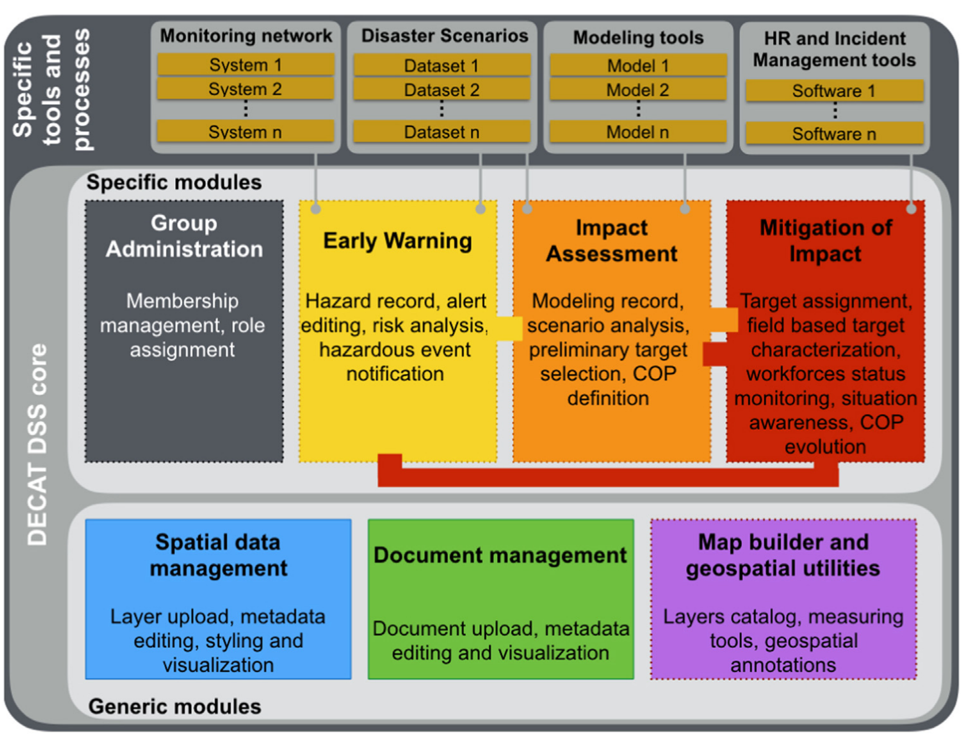

Fig. 2. Functional decomposition of the DECAT SDSS.

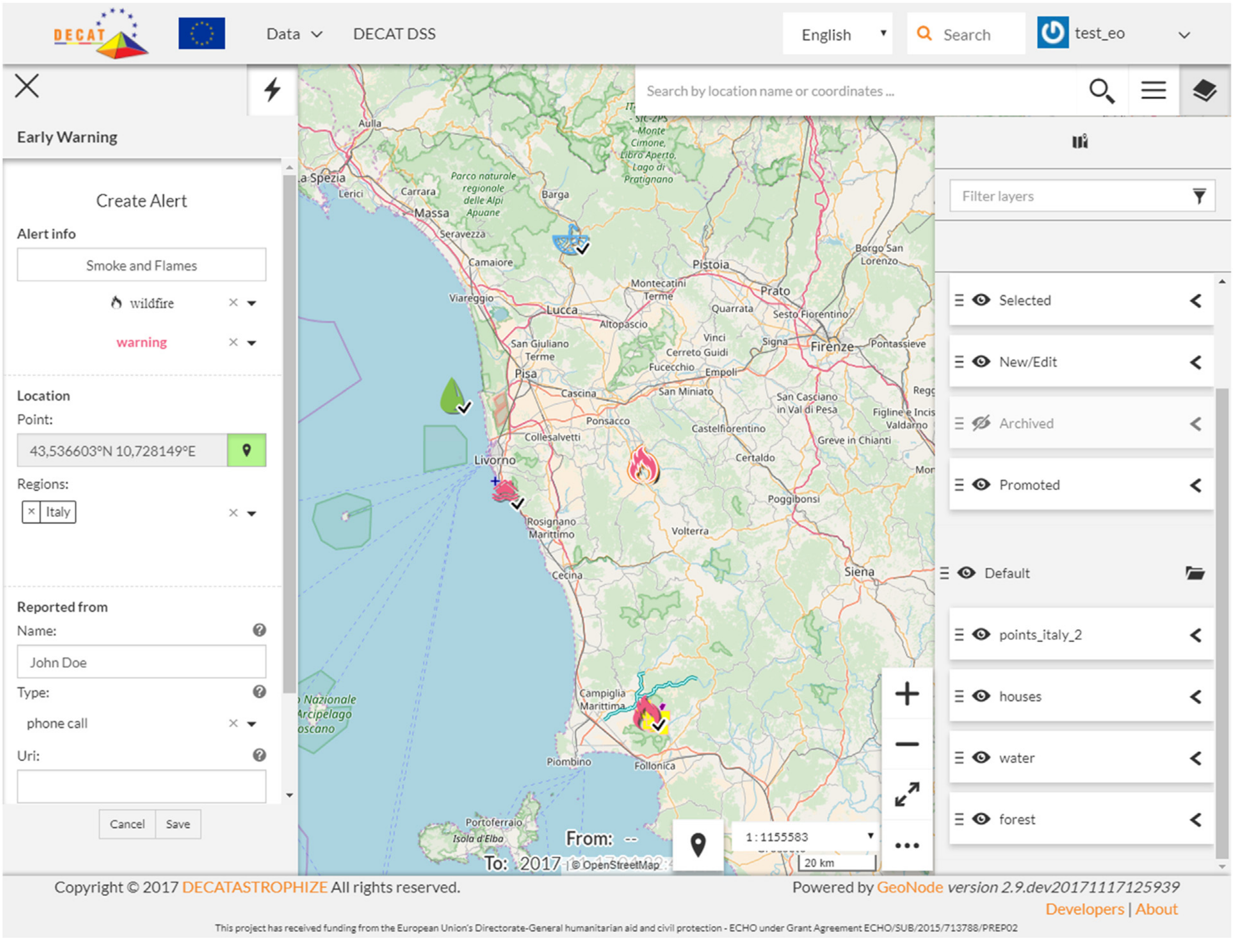

Fig. 3. User interface for event operator.

evolution, supporting an iterative workflow which involve repeated interaction among Early Warning updates, Impact Assessment re-evaluations and Emergency management evolution.

3.4. Technology framework

The DECAT SDSS foundations are represented by a few on well-known Open Source products as building blocks like GeoServer, GeoNode and MapStore, as shown in Fig. 6. GeoServer provides advanced geospatial data management and mapping capabilities according to the OGC Web Map Services (WMS) [20], Web Coverage Services (WCS) [3] and Web Feature Services (WFS) [44] protocols while GeoNode acts as a broker for the data providing OGC Catalog Services (CSW) [28], capabilities, acting as the catalog for data and metadata discovery. MapStore is used as the mapping and visualization engine and provides geospatial visualization functionalities over the data ingested into the SDSS by interacting with OGC protocols.

Authentication is provided through the support for OAUTH 2.0 [17] protocol having GeoNode play the provider role (i.e. being responsible for the management of users' credentials and live sessions) hence it takes care of creating and expiring users' sessions as well as of managing access permission over the ingested geospatial data in coordination with GeoServer. In its default configuration data is private and accessible only to the publisher and the users within his organization. Several additional modules have been implemented during the project to create the DECAT DSS by extending the GeoNode and MapStore frameworks. The user-interface has been completely redesigned to follow a three phases approach during the management of the emergency, where specific back-end modules have been developed in GeoNode to manage alerts and hazards, to perform and disseminate impact assessments associated to hazards, up to the annotations used by emergency managers to support resource allocation to targets in the field.

4. Results

4.1. Functionalities review and potential evolutions

There is room for improvement and potential for evolutions in several places of the platform. In the current version the "Event Operator" is responsible for entering in the platform relevant events that have been collected outside the platform thus providing an initial filtering and validation on the received warnings; experimental work has been performed in order to allow the platform to collect information from external sources like Twitter, SMS as well as emails but due to time and budget constraints these functionalities have not been brought to production quality and therefore used in the real world scenarios.

In this phase, the role of crowdsourced information can play an important role hence we believe that further resources could be devote to open this module to the collection of early warnings from citizens (using them as sensors), however proper validation should be put in place to filter reports both in terms of software unsupervised validation as well as human supervised validation, given the sensitive nature of this information as well as the critical importance of the whole workflow, once activated: avoiding false alarms is, obviously, a key concern.

The "Impact assessment" module allows the "Impact assessor" to create and update the so- COP for the emergency managers to capture the evolution of the hazards by integrating relevant hazard models' outputs.

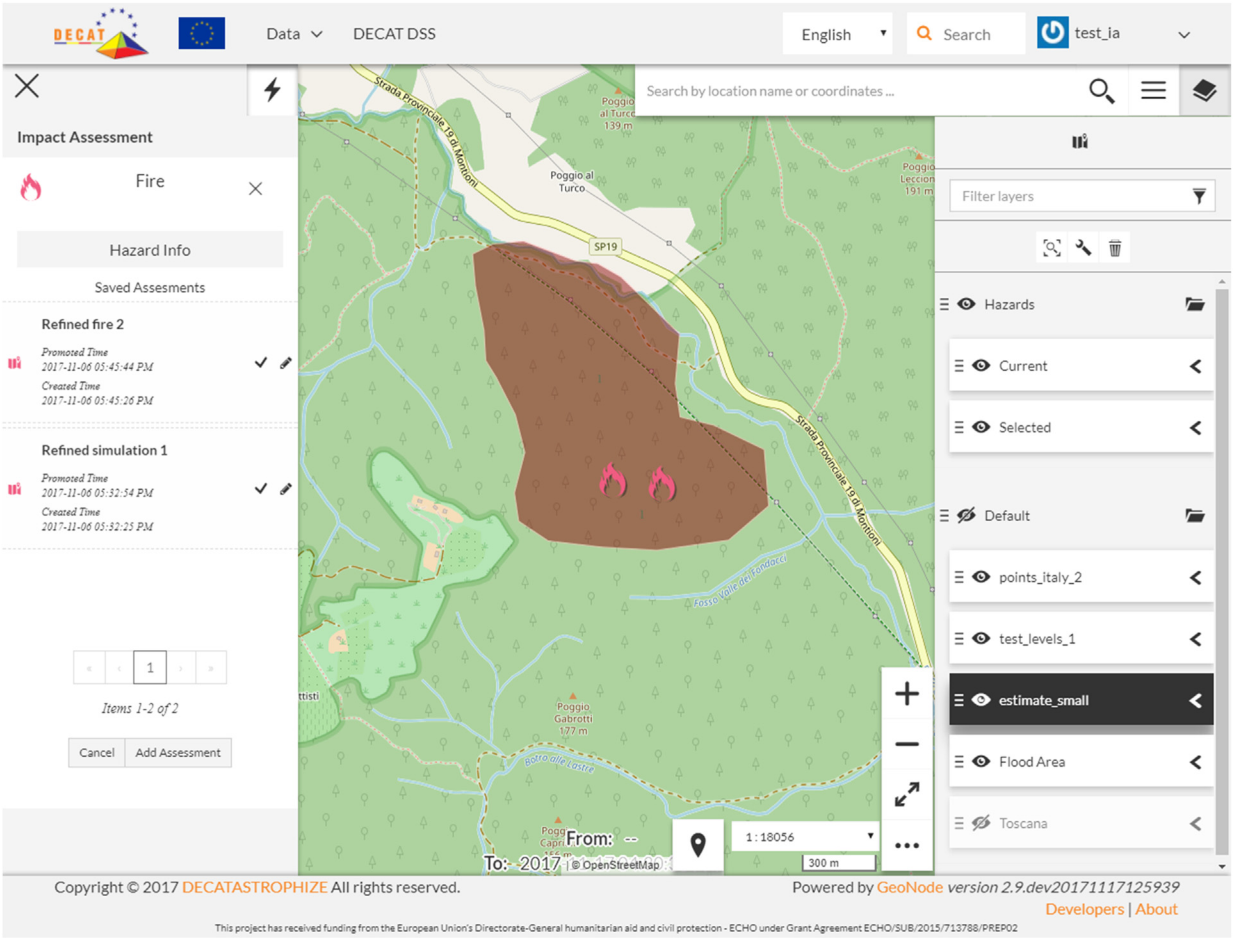

Fig. 4. User interface for impact assessor.

At the time of writing the platform accounts for the possibility to extract outputs from OGC WPS (we successfully tested an integration with BRGM Seismic Model) processes as well as to manually or programmatically (via a REST API) upload model outputs for models that are not (or cannot, i.e. if they are implemented as desktop tools which is very frequent) exposed as WPS processes. The ability to run hazards models directly inside the platform has been designed and prototyped but it has not been brought to production quality due to time and budget constraints; a natural evolution of this module would be adding this capability in addition to the existing ones above in order to host and exploit a catalog of well-known models for hazards.

As far as the "Emergency Management" is concerned, we focused on the development of an online collaborative map the allocated resources where managers of different forces of intervention could do light coordination in real-time using the same exact COP made with up-to-date information provided by the hazard expert (i.e. the impact assessor) to guide their decisions. The natural evolution of this module would be the ability to bring this information to the field and gather feedback back from the field to drive the whole workflow; in order to do this, we designed and prototyped a simplified mobile version of the geospatial annotations that could be used from field personnel to receive notifications as well as to send notifications and update information in real-time. Once again, crowdsourcing information in real-time about the impact of the disaster is of critical importance together with the ability to execute hazards' models directly in the platform since we could short-circuit the two and provide more refined impact assessments over time as field personnel is involved in the emergency management.

4.2. Putting the platform to the tests

A Table Top / Command Post exercise was conducted in the area of Paphos, Cyprus to assess the transferability and utility and of the GE-DSS in disaster preparedness and response. The main objective of the exercise was to test each GE-DSS in realistic scenarios to ascertain that they can enhance decision making in emergency situations. This test helped examining the added value of the GE-DSS framework in decision making. The hazards tested during the scenarios were wildfires in Argaka village (Fig. 7 $_{\text{right}}$) and floods in the city of Paphos (Fig. 7 $_{\text{left}}$).

Representatives of different Governmental Departments participated in the exercise as members of the Emergency Coordination Center (ECC). According to the National Emergency Response Plans for forest fires, Urban and Rural fires and extreme weather conditions, these Governmental Departments undertook their role in preparedness and response during these disasters.

Based on the overall scenario, a fire started near a village less than 2 km from the forest. Due to the high temperatures, the terrain of the area (pine trees) and the long period of drought, the fire was very quickly developed into a large-scale forest fire, threatening the forest of Paphos, nearby villages and other infrastructure. While all Governmental Departments are responding to the fire developing their resources, a forecast from the Meteorological Department predicts heavy rainfall in the Town of Paphos with a great danger for floods. The flood models were used to show which areas would suffer from the flood in order to assist the various departments to respond in the most effective way. Below, Fig. 8, shows all the steps (workflow) followed during a multi-hazard scenario that took place in Paphos for the TTX. It can be seen in the first step (Early Warning) the incoming information

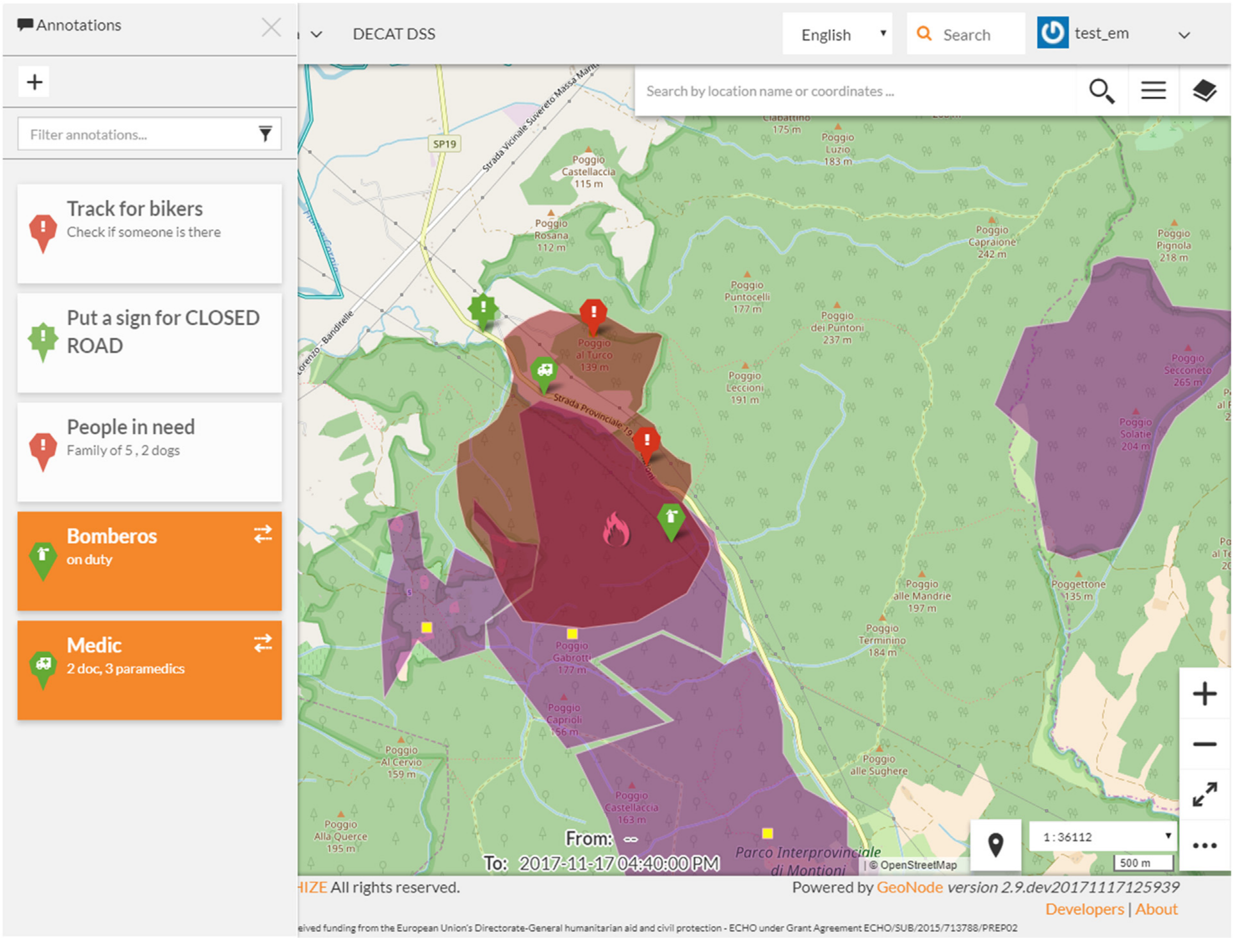

Fig. 5. User interface for emergency manager.

came from two different agencies. In the case of wildfires, the Department of forests gave the information, while in the case of floods the Meteorological Department gave the information. These departments created the event, updated it and promoted it to the next step (Impact Assessment). CCD was the administrator (for the TTX) of the second step where they followed different procedure in the two hazards as it can be seen in Fig. 8. The third step was controlled by the whole coordination centre where actions/requests took place, such as use of aerial means, ground forces, evacuations, shelters, first aid, etc.

During the whole exercise, an Exercise Control Team (ExCon) consisted of Civil Defence Officers was used for the better control and execution of the exercise. The Team was providing the incoming information to the participants, based on which they had to take decisions. The information was given to the members of the

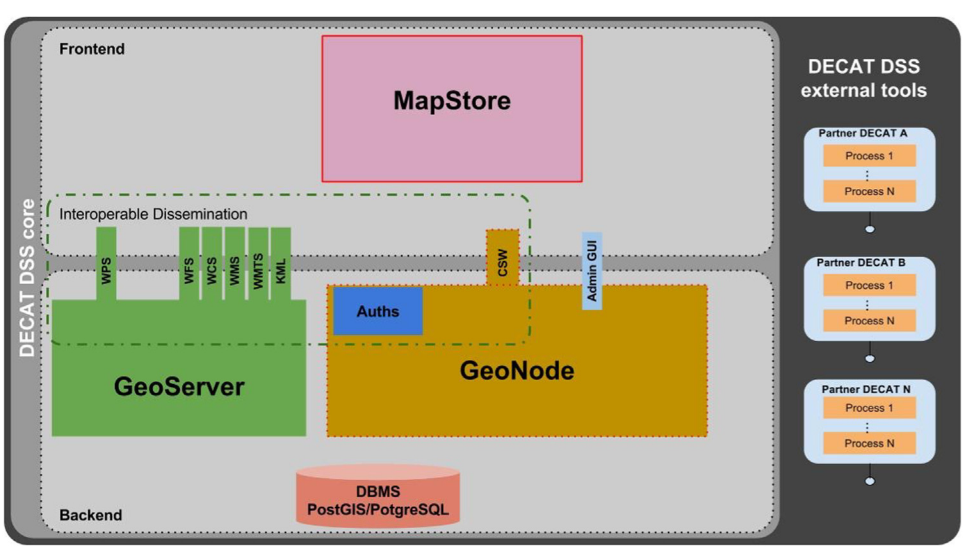

Fig. 6. Technology viewpoint for the DECAT SDSS.

Fig. 7. Flood (left) and fire (right) hazards in DECAT TTX that took place in Paphos.

Coordination Centre in power point projections in constant flow. A supporting team of trained users of the platform was assisting the participants to extract information from the GE-DSS. Meanwhile, a Communication Centre was set to assist the participants communicating with the headquarters of their departments / services.

Electronic equipment was used (computers, projectors etc.) to assist the participants to visualize the disaster's prediction and have immediate information of the available resources. The DECAT DSS was used in various occasions in order to extract and provide valuable information to the decision makers therefore decisions were made based on this information. All the three phases of the platform were used and successfully presented (Early Warning, Impact Assessment and Emergency Management).

In the case of the forest fire, apart from confronting the fire impact, the evacuation of some areas was needed. In this case, DECAT DSS gave valuable information on where to accommodate the evacuees, how to transfer them, available and safe road network, available resources etc. Using the prediction of the flood's model, the ECC was able to take important decisions on which areas needed to be evacuated, which infrastructure would be affected and needed to be protected, areas which would be severely flooded etc.

In light of the fact that Cyprus Civil Defence had never used a GIS based system in TTX's or CPX's, the DECAT DSS was the first application, use and testing of a system in realistic scenarios to ascertain that they can enhance decision making in emergency situations. Other TTX case studies conducted by agencies with more experience in using such tools (France, Hungary, Italy, and Spain) demonstrated the utility of the developed platform. In any case, the TTX conducted in Crete, Greece 1) was a more thorough case study, 2) demonstrated the advantages of their platform over others as the TTX included different and multiple disaster/hazard scenarios, and 3) showed that the proof of concept was helpful in facilitating uptake of the technology: several stakeholders were interested in adopting or incorporating it into their existing system, including Civil Protection of Crete since the platform provides an integrated tool for the management of the emergency lifecycle which is crucial to rationalize and coordinate efforts from various actors involved.

In addition, DECAT has added value to develop the capacity of a transnational partnership is to bring together experts with special skillsets in various aspects of civil protection in EU Member-States and neighboring countries to develop a software that can be transferred to any other hazard or Member-State. The technological innovation and solution includes the partners in each country using existing models/systems in an integrative and synergistic way to develop one multi-platform distributed and integrated framework which can be deployable and transferable.

5. Discussion and conclusions

Faced with a large amount of simultaneous spatial information and data on natural disasters and hazards, obtaining and utilizing this information and providing effective support for disaster risk mitigation or reduction urban planning is becoming an increasingly difficult challenge. The effectiveness of a SDSS and making informed decisions can be greatly enhanced by providing Civil Protection professionals, policy makers, and other stakeholders with methods and tools to evaluate the different impacts of proposed decisions in all phases of the disaster management cycle and emergency management. These methods and tools should rely on indicators that can be easily measured and monitored over time. Incorporating different spatial data and models for decision making in disaster management processes using a SDSS in a use case approach provides an effective means to address this challenge,

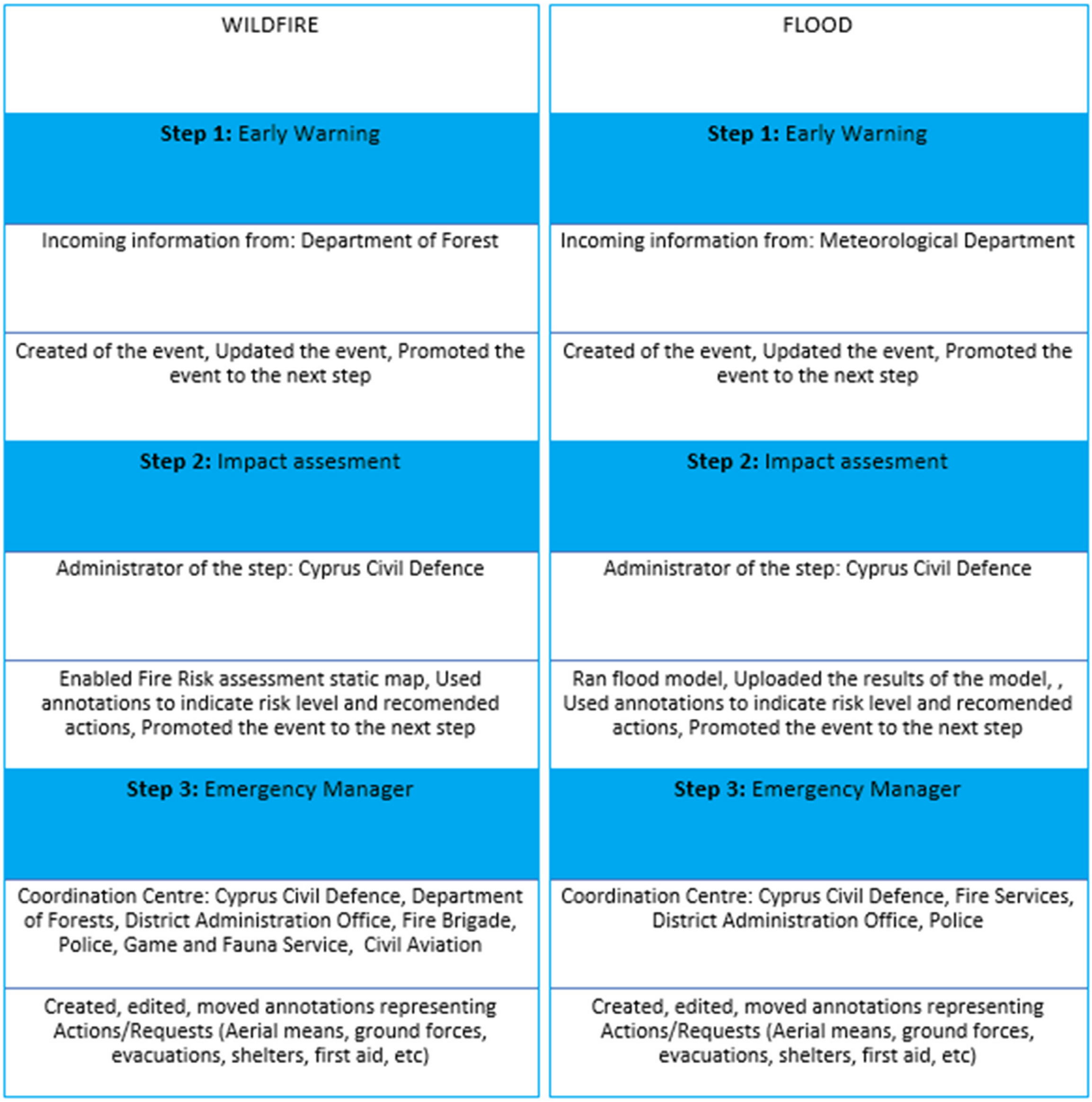

Fig. 8. Steps followed during the exercise in Paphos (Left: Steps regarding the wildfire hazard, Left: Steps regarding the flood hazard).

and SDSS applications are increasingly being used to develop and demonstrate the effectiveness of such systems. Existing capabilities of a SDSS can provide effective strategic decision support to Civil Protection authorities and private and public organizations and assist them in enhancing their information infrastructure.

This paper provides a review of how the development and utilization of an effective SDSS and related tools simulated and assessed different aspects of disaster or multi-hazard scenarios in a use case (study) approach by conducting TTX's.

The DECAT GE-DSS GIS facilitated the online monitoring of status of the TTX's. As the exercise or work was completed and identified, it could visually display current hazard and risk status. As the status changed, information was quickly updated, and the current status could easily be viewed and accessed at the centralized GIS interface or view in the EOC. The GE-DSS allowed disaster managers to quickly access and visually display critical information by location and make quicker decisions. The GE-DSS deployed in the EOC, the nerve centre of all activity in case of a disaster, facilitates the development of action plans that are transmitted to disaster response personnel for the coordination and implementation of emergency efforts and for static or dynamic monitoring.

The key advancements in the DECAT platform and GE-DSS technology played a key role in the GIS based information systems, the main support of EOCs being web-based geo-processing, geo-visualization and the geo-database. Each stakeholder or user of the GE-DSS in the E.O.C. has/had the knowledge, skill and ability to make better and more informed decisions.

Today, GIS technology that supports distributed networks of shared web services, and even the networking of networks-like the linking of Federal, State, and Local web services, is growing dramatically. Many are interested in combining their enriched GIS datasets into comprehensive coverages for larger areas that are multipurpose and can serve the needs of numerous organizations and applications.

The software technology in the DECAT platform and GE-DSS aligned with and adopted three fundamental ICT strategies. The first one is considering engineered and integrated system and workflow to modern IT standards: multi-layer architectures (data, models and application servers, many stakeholders and users). The second ICT strategy achieved is the support for data interoperability, types, formats, and sources, used on an emergency basis, while the third one considers the support for multi-participant access, users collaborating on maps, data, and spatial information via the web for “federated” civil protection

agencies—those that have joined together for common purpose workflows. Such strategies form the context for how the comprehensive and integrated GIS technology can be deployed for Early Warning, Impact Assessment and in Emergency Management, and the core of any Emergency Operations Centre's Information System.

Natural disasters and hazards are inevitable, and it is almost impossible to fully recoup the damage caused by the disasters, however a result of the effectiveness of the DECAT DSS, it is possible to mitigate the potential risk by developing disaster early warning strategies, preparing and implementing developmental plans to mitigate the impacts from disasters and hazards and support emergency management operations. Disaster response and recovery efforts require timely interaction, decision making and coordination of public emergency services in order to save lives and property. Today, GIS tools are used in this field only to a limited extent, but with the proper application or use, it is a tremendous potential for increasing efficiency and effectiveness in coping with a disaster. The prime concern during any disaster or hazard is the availability of the spatial information, and the dissemination of this information to all concerned.

Through the demonstration of the DECAT DSS, simultaneous natural hazard information retrieval and placement of spatial data on a common geographic location allowed for rapid overlays and correlation of similar and diverse datasets. This engaged different users, ranging from academic specialists to stakeholders and elected and appointed officials seeking general information about natural hazards and examining local vulnerabilities. The assembly of this information resulted in multiple hazards occurring over different geographic areas and over different time scales to be collected in a single common environment.

As a relatively small island, Cyprus is exposed to diverse types of natural hazards, ranging from earthquakes to fire and flood events which can cause much damage to human life and property. With a diverse geological character, various parts of the island are at varying degrees of risk to these hazards. However, with continued growth in population and demand on land resources, developments have increasingly placed more people and infrastructure at direct risk from natural hazards, and their impacts have become more severe.

In Cyprus, many researchers and government agencies created different datasets and static and dynamic maps on the different hazards, at different scales, ranging from regional to local scales. As a result, much information existed. However, it didn’t exist within a single common database, nor did it have the capacity for the simultaneous overlay of the information in a common view, resulting in users having to sift through many different maps and reports. Dialog commands in a TTX and a Command Post Exercise (CPX) allowed the user to use the GE-DSS to search for information by location or by type of hazard, with the requested information appearing on the base map. Users were also able to see a map associated with a location to evaluate that natural hazard history of the location. Associated GIS data layers, such as topographic features, flood data and infrastructure networks also provided background information about the landscape area of interest of each user.

Five other case studies or TTX's conducted in France, Greece, Hungary, Italy and Spain also illustrated the utility of the platform and the capabilities of a SDSS applications to simulate specific hazard scenarios. Reports on these case studies present and analyze the methodologies in the use-case approach not only as “proof of concept” but as a means to link it to the development of an effective SDSS in utilizing GIS capabilities to assess different disasters or multi-hazards. The exercise in Crete, being relatively more thorough, demonstrated how the DECAT DSS could be effectively used in different disaster and multi-hazard scenarios as it validated the advantages of the platform. To elaborate the case scenario, the purpose of the TTX in Crete was to demonstrate the DECATASTROPHIZE FRAMEWORK in earthquake/tsunami, wildfire and marine pollution-oil spill scenarios. The main objective of the TTX was to orient the involved parties with the use of the DECAT common operational procedure for addressing multiple natural disasters. Three scenarios were involved: a) an Earthquake / Tsunami event on the western coast of Crete, b) the occurrence of forest wildfire in the Prefecture of Heraklion and c) a marine pollution oil-spill incident on the northern coast of Crete near the port of Heraklion. The TXX was jointly organized by the Technical University of Crete and the Institute of Applied and Computational Mathematics - Foundation for Research and Technology-Hellas. Comments on the TTX and lessons learned from it include the following: 1) the Platform provides useful information for utilization in the field, although diligent training is required in order to be easily handled in a time of crisis and by a substantial number of civil protection executives, 2) several public services are already equipped with analogous platforms, where their resources appear in real-time, but this platform could function in a secondary manner because it provides layered data as well as the time evolution of an event, 3) multiple services were interested in the platforms ability to incorporate spatial and time-evolving data and they were interested in uploading their information database into the Platform, providing that any sensitive information is restricted at all times, 4) for earthquake and tsunami events, the response times are very restrictive and data and crisis management can only be assessed after those events, 5) it would be a good idea to standardize the whole platform and use automated inputs (e.g. satellite imagery, automatic warning pop-up messages from the local Civil-Protection authority, etc.) for immediate monitoring of the situation and as much co-ordination as possible for staff and equipment.

The DECAT DS S, i.e., a SDSS a through the use-case approaches illustrated herein, represents a step forward in efforts to effectively account for the spatial dimension in the development and implementation of a DECAT platform and tool for the management of disasters or multiple hazards. The link between the use case approach leading to the development of an effective SDSS that can be used to simulate specific scenarios depending on the hazards in any country. It helps Civil Protection authorities, policymakers and practitioners access, interpret and understand information from data, analyses and models, and guide them in identifying possible actions during a decision-making process.

The DECAT DSS clearly emerged as a very important tool for effective planning, communication, and training in the various stages of the disaster management cycle. It can now be used to provide the background knowledge to inform them about the location and guide them to make better and further decisions associated with each hazard or disaster.

In summary, this paper described the role of web-based GIS in evolving a suitable strategy for disaster management, DRR and occupational framework and workflows for their monitoring, assessment and mitigation. The project demonstrated through TTX how the DECAT DSS can fulfill data requirement needs for early warning, impact assessment, mitigation and planning and emergency operations and how it can become the backbone of DRR and emergency management.

Acknowledgement

This project has received funding from the European Union's Directorate-General humanitarian aid and civil protection (DG-ECHO) under Grant Agreement ECHO/SUB/2015/713788/PREP02.

References

[1] R. Abdalla, Evaluation of Spatial Analysis Application for Urban Emergency Management 5 Springer International Publishing, 2016, p. 2081.
[2] D.D. Alexakis, A. Agapiou, M. Tzouvaras, K. Themistocleous, K. Neocleous, S. Michaelides, D.G. Hadjimitsis, Integrated use of GIS and remote sensing for monitoring landslides in transportation pavements: the case study of Paphos area in Cyprus, Nat. Hazards 72 (1) (2014) 119–141.
[3] P. Baumann, OGC® WCS 2.0 Interface Standard- Core: Corrigendum. Open Geospatial Consortium, 2012.
[4] D. Bausch, HAZUS: FEMA’s GIS-based risk assessment tool. GITA conference (Geospatial Information & Technology Association), 2003.
[5] M. Bonazountas, D. Kallidromitou, P. Kassomenos, N. Passas, A decision support

system for managing forest fire casualties, Environ. Manag. 84 (4) (2007) 412–418.
[6] K. Boyd, R. Hervey, J. Stradtner. Assessing the vulnerability of the Mississippi Gulf coast to coastal storms using an on-line GIS-based coastal risk atlas. In: Proceedings of Oceans Conference Record (IEEE), 2(April), 1127–1133.
[7] E. Chuvieco, I. Aguado, S. Jurdao, M.L. Pettinari, M. Yebra, J. Salas, S. Hantson, J. de la Riva, P. Ibarra, M. Rodrigues, M. Echeverria, D. Azqueta, M.V. Roman, A. Bastarrika, S. Martinez, C. Recondo, E. Zapico, F.J. Martinez-Vega, Integrating geospatial information into fire risk assessment, Int. J. Wildland Fire 23 (5) (2014) 606.
[8] J.D. Colby, K.A. Mulcahy, Y. Wang, Modeling flooding extent from Hurricane Floyd in the coastal plains of North Carolina. Global Environmental Change Part B: Environmental Hazards, No longer published by Elsevier, 2(4), 157–168, 2000.
[9] A. Damalas, Mapping and digitizing watershed and sub-watershed hydrologic unit boundaries for flood risk management. Natural Resources Conservation Service, Missouri State Office, Columbia, Missouri. Prepared under National Instruction No. 170-304, 1992.
[10] I.H. EL-Gamily, G. Selim, E.A. Hermas, Wireless mobile field-based GIS science and technology for crisis management process: a case study of a fire event, Cairo, Egypt, Egypt. J. Remote Sens. Sp. Sci. 13 (2010) 21–29.
[11] FEMA. (2002). "Federal Emergency Management Agency (2002–2017)".
[12] T.G. Frazier, N. Wood, B. Yarnal, Stakeholder perspectives on land-use strategies for adapting to climate-change-enhanced coastal hazards: Sarasota, Florida, Appl. Geogr. 30 (2010) 506–517.
[13] T. Frazier, N. Wood, B. Yarna, Utilizing GIS to identify vulnerability to coastal inundation hazards: a case study from Sarasota County, Florida. In: Fra Paleo, U. (Ed.), Building Safer Communities. Risk Governance, Spatial Planning and Re-sponses to Natural Hazards. IOS Press, Amsterda, 2009.
[14] C. Geiß, H. Taubenböck, Remote sensing contributing to assess earthquake risk: from a literature review towards a roadmap, Nat.Hazards 68 (2013) 7–48.
[15] I.Z. Gitas, J. San-Miguel-Ayanz, E. Chuvieco, A. Camia, Advances in remote sensing and GIS applications in support of forest fire management, Int. J. Wildland Fire 23 (2014), p. 603.
[16] Y. Guzman-Tapia, M.J. Ramirez-Sierra, J. Escobedo-Ortegon, E. Dumonteil, EFFECT OF hurricane ISIDORE ON TRIATOMA DIMIDIATA distribution AND CHAGAS disease transmission risk IN THE YUCATÁN peninsula OF MEXICO, Am. J. Trop. Med. Hyg. 73 (6) (2005) 1019–1025.
[17] D. Hardt, The OAuth 2.0 Authorization Framework. Internet Engineering Task Force (IETF), 2012.
[18] IN-MHEWS, 'International Network for Warning Systems - Multi-Hazard Early'. A Multi-Stakeholder Partnership for Promoting and Sharing Best Practice in Multi-Hazard Early Warning Systems and Services for Disaster Risk Reduction and Resilience, 2015.
[19] K.P. Krishnamurthy, J.B. Fisher, C. Johnson, Mainstreaming local perceptions of hurricane risk into policymaking: a case study of community GIS in Mexico, Glob. Environ. Change 21 (2011) 143–153.
[20] J. De la Beaujardiere, OpenGIS® Web Map Server Implementation Specification, Open Geospatial Consortium Inc, 2006.
[21] M. Lazzari, P. Salvaneschi, Embedding a geographic information system in a decision support system for landslide hazard monitoring, Nat. Hazards 20 (1999) 185–195.
[22] X. Li, D. Hisdal, H.W. Utter, VALUE OF IFSAR GEOSPATIAL PRODUCTS AND SERVICES FOR EMERGENCY MANAGEMENT, 2012.
[23] K. Liu, Y. Yao, D. Guo, On managing geospatial big-data in emergency management. in: Proceedings of the 1st ACM SIGSPATIAL International Workshop on the Use of GIS in Emergency Management - EM-GIS '15, ACM Press, New York, New York, USA,2015, pp. 1–4.
[24] G. Mallinis, I.Z. Gitas, V. Giannakopoulos, F. Maris, M. Tsakiri-Strati, An object-based approach for flood area delineation in a transboundary area using ENVISAT ASAR and LANDSAT TM data, Int. J. Digit. Earth (2011) 1–13.
[25] H.C. Merrett, W.W. Chen, Applications of geographical information systems and remote sensing in natural disaster hazard assessment and mitigation in Taiwan, Geomat., Nat. Hazards Risk 2 (2012) 145–163.
[26] C. Mettas, A. Agapiou, K. Themistocleous, K. Neocleous, D. Hadjimitsis, S. Michaelides, Risk provision using field spectroscopy to identify spectral regions for the detection of defects in flexible pavements, Nat. Hazards (2016) 1–14.
[27] National Reasearch Council, Successful Response Starts with a Map, National Academies Press, Washington, D.C, 2007.
[28] D. Nebert, A. Whiteside, P. Vretanos, OpenGIS ® Catalogue Services, Open Geospatial Consortium Inc, 2007.
[29] J.P. Newman, H.R. Maier, G.A. Riddell, A.C. Zecchin, J.E. Daniell, A.M. Schaefer, H. van Delden, B. Khazai, M.J. O'Flaherty, C.P. Newland, Review of literature on decision support systems for natural hazard risk reduction: current status and future research directions, Environ. Model. Softw. 96 (2017) 378–409.
[30] NGAC, EMERGING TECHNOLOGIES AND THE GEOSPATIAL LANDSCAPE., 2016.
[31] G. O'Hare, Hurricane 07B in the Godavari Delta, Andhra Pradesh, India: vulnerability, mitigation and the spatial impact, Geogr. J. 167 (2001) 23–38.
[32] Organization of American States - OAS, Primer on Natural Hazard Management in Integrated Regional Development Planning PREFACE PART I - INTEGRATED DEVELOPMENT PLANNING AND NATURAL HAZARDS CHAPTER 1 - INCORPORATING NATURAL HAZARD MANAGEMENT INTO THE DEVELOPMENT PLANNING PROCESS A. what are natura, 1991.
[33] B.K. Paul, Environmental Hazards and Disasters. Environmental Hazards and Disasters: Contexts, Perspectives and Management, John Wiley & Sons, Ltd, 2011.
[34] R.A. Pielke, J. Rubiera, C. Landsea, M.L. Fernández, R. Klein, Hurricane vulnerability in Latin America and The Caribbean: normalized damage and loss potentials, Nat. Hazards Rev. 4 (3) (2003) 101–114.
[35] M.R. Rahman, Z.H. Shi, C. Chongfa, Z. Dun, Assessing soil erosion hazard – a raster based GIS approach with spatial principal component analysis (SPCA), Earth Sci. Inform. 8 (2015) 853–865.
[36] P. Schut, OpenGIS ® Web Processing Service. Open Geospatial Consortium, 2007.
[37] C.L. Sian, N. Muhamad, Integrated and Multi-Hazard Disaster Management. GeoSmart Asia 2016: GI for Disaster Preparedness and Risk Reduction, 2016.
[38] A. Taramelli, L. Melelli, M. Pasqui, A. Sorichetta, Modelling risk hurricane elements in potentially affected areas by a GIS system, Geomat., Nat. Hazards Risk 1 (2010) 349–373.
[39] A. Taramelli, E. Valentini, S. Sterlacchini, A GIS-based approach for hurricane hazard and vulnerability assessment in the Cayman Islands, Ocean Coast. Manag. 108 (2015) 116–130.
[40] P. Tarolli, M. Cavalli, Encyclopedia of Natural Hazards. (November 2016), 2013.
[41] D.S.K. Thomas, K. Ertugay, S. Kemec, The Role of Geographic Information Systems/Remote Sensing in Disaster Management, Disaster Research, Springer, New York, NY, 2007, pp. 83–96.
[42] P. Tran, R. Shaw, G. Chantry, J. Norton, GIS and local knowledge in disaster management: a case study of flood risk mapping in VietNam, Disasters 33 Blackwell Publishing Ltd, 2009, pp. 152–169.
[43] UNISDR, ''United Nations International Strategy for Disaster Reduction''. Development of the Sendai Framework Words into Action'' Implementation Guide for Multi-Hazard Early Warning Systems and Multi-Hazard Management of Disaster Risk Reduction, 2016.
[44] Vretanos, P. (2014). OpenGIS Web Feature Service 2.0 Interface Standard. *Open Geospatial Consortium Inc*.
[45] C.C. Watson, M.E. Johnson, Hurricane loss estimation models: Opportunities for improving the state of the art, Bull. Am. Meteorol. Soc. 85 (11) (2004) 1713–1726.
[46] WDD,''Water Development Department''. 〈http://www.moa.gov.cy/moa/wdd/Wdd.nsf/index_en/index_en?OpenDocument〉.
[47] C.van. Westen, Multi-hazard risk assessment. RiskCity Exercise book, 2009.